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TECHNICAL REPORT
EP-131

EFFECTS OF HIGH AND LOW HUMIDITY ON HEAT EXCHANGES OF LIGHTLY CLOTHED MEN

QUARTERMASTER RESEARCH & ENGINEERING CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

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Quartermaster Research & Engineering Center
Natick, Massachusetts

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EFFECTS OF HIGH AND LOW HUMIDITY ON HEAT EXCHANGES OF LIGHTLY CLOTHED MEN

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FOREWORD

ALTHOUGH BEING "CHILLED-TO-THE-BONE" IN COLD-WET ENVIRONMENTS HAS BEEN COMMONLY EXPERIENCED, THE FACTORS RESPONSIBLE FOR THE COLD STRESS HAVE NOT BEEN IDENTIFIED. A PREVIOUS INVESTIGATION WAS UNDERTAKEN TO DETERMINE THE EXTENT TO WHICH VARIOUS HUMIDITIES ALTERED BODY COOLING OF NUDE MEN DURING EXPOSURE TO CONDITIONS CONSIDERED TO BE IN THE COLD-WET RANGE. RESULTS SHOWED THAT THERE WAS NO EFFECT OF HUMIDITY ON THE PHYSIOLOGICAL RESPONSES MEASURED. THEREFORE, THE PRESENT STUDY WAS UNDERTAKEN TO DETERMINE WHETHER THERE WAS AN INTERACTION BETWEEN CLOTHING AND HUMIDITY WHICH MIGHT PROVIDE A BASIS FOR "COLD-WET" CHILL.

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ABSTRACT

SIX HEALTHY YOUNG MEN WERE EXPOSED, LIGHTLY CLOTHED, TO VARIOUS COMBINATIONS OF WIND (< 1 AND 10 MPH), TEMPERATURE (40 AND 50°F) AND RELATIVE HUMIDITY (30 AND 100%). SKIN AND RECTAL TEMPERATURES AND OXYGEN CONSUMPTION WERE RECORDED. THE RESULTS SHOW THAT RELATIVE HUMIDITY HAD NO EFFECT ON THE PHYSIOLOGICAL RESPONSES MEASURED, WHEREAS WIND AND DRY BULB TEMPERATURE HAD MARKED EFFECTS. THIS FOLLOWS THE PATTERN SEEN WHEN MEN WERE EXPOSED WITHOUT CLOTHING, AND INDICATES THAT, UNDER CHAMBER CONDITIONS, THERE IS LITTLE INTERACTION BETWEEN CLOTHING AND HUMIDITY THAT COULD ACCOUNT FOR COLD-WET "CHILL". THE IMPORTANCE OF CONSIDERING RADIATION IN ANY COMPARISON OF COLD-WET AND COLD-DRY ENVIRONMENTS IS DISCUSSED.

EFFECTS OF HIGH AND LOW HUMIDITY ON HEAT EXCHANGES OF LIGHTLY CLOTHED MEN

1. Introduction

Various workers (1, 2) have investigated the effects of high humidity and low ambient temperatures on the heat exchanges of nude men during acute exposures. The results of a recent study from this laboratory (1) showed that the physiological and subjective responses of nude men were similar during exposure to high and low humidity conditions, i.e., there was little evidence for the sensation of being more "chilled" during exposure to conditions which are frequently referred to as "cold-wet". We suggested, as did others (2), that it was necessary to study the responses of the clothed man before ruling out a physiological basis for cold-wet sensations.

The purpose of the present study was to determine whether lightly clothed men would exhibit differences in their physiological responses when exposed to cold with low and high humidities. These differences, if they occurred, could then provide a physiological basis for the increased sensation of "chill" on cold-wet days.

2. Experimental Design

Six healthy young soldiers, lightly clothed,* were exposed in a chamber to various combinations of the following:

Dry Bulb: 50 and 40°F
Relative Humidity: 100 and 30%
Windspeed: 10 and < 1 mph

All men were simultaneously exposed to a given set of conditions and the order of conditions was randomized (Table 1). Exposure to each set of conditions was for two hours; exposure was preceded by a one-hour control period at 78°F, 50% R.H. The subjects rested quietly (semi-reclining poistion) during both control and exposure periods. The daily schedule is shown in Table II. The experiment was conducted during the month of May.

The following measurements were made: skin temperature, rectal temperature (T_R), and oxygen consumption ($\dot{V}O_2$). Details of methods are given elsewhere (1). The same shorthand notation for describing environmental conditions will be used (1), e.g., 40/30/10 signifies dry bulb temperature 40°F, relative humidity 30%, and windspeed 10 mph. Comparison of the physiological responses to the various conditions was made by analysis of variance (3).

*Cotton undershorts, cotton T-Shirt, low quarter shoes, socks, cotton shirt, and cotton trousers.

TABLE I: EXPECTED AND ACTUAL CHAMBER CONDITIONS

	Day 1	2	3	4	5	6	7	8
				Dry Bulb, °F.				
Expected	50.0	40.0	40.0	50.0	40.0	50.0	50.0	40.0
Actual	50.0	40.0	40.0	50.0	40.0	50.0	50.0	41.0
				Wet Bulb, °F.				
Expected	38.7	39.4	39.4	49.3	31.1	49.3	38.7	31.1
Actual	39.0	40.0	40.0	50.0	32.0	50.0	39.0	31.8
				Relative Humidity, %				
Expected	30	95	95	95	30	95	30	30
Actual	32	100	100	100	37	100	32	30
				Vapor Pressure, mm Hg				
Expected	2.8	6.0	6.0	8.8	1.9	8.8	2.8	1.9
Actual	3.0	6.3	6.3	9.2	2.3	9.2	3.0	2.0
				Windspeed, mph				
Expected	10	10	< 1	10	< 1	< 1	< 1	10
Actual	10	10	< 1	10	< 1	< 1	< 1	10

TABLE II: DAILY SCHEDULE

Time Hours	Procedure
2300	Retire for night
0730-0800	Arise, Ablutions
0800-0830	Report to control chamber, put on skin temperature harness and rectal catheter; put on clothing which has been conditioned in the control chamber overnight. No smoking allowed.
0830-0900	Rest quietly (semi-recline) in chairs
0900-0930	Control measurments
0930-0935	Subjects wheeled in chairs into test chamber
0935-1135	Test measurements
1135	End of test

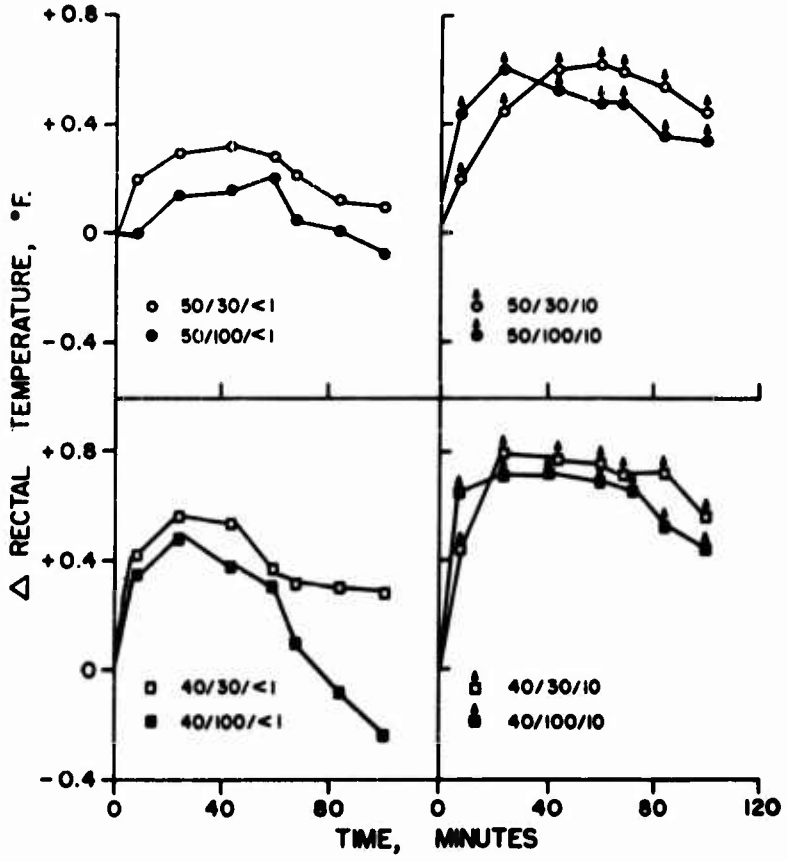

FIGURE 1. AVERAGE CHANGE IN RECTAL TEMPERATURE OF 6 MEN DURING EXPOSURE TO COLD AND HIGH AND LOW HUMIDITIES

3. RESULTS

A. RECTAL AND SKIN TEMPERATURES

IN GENERAL, T_R INCREASED DURING THE FIRST HOUR OF EXPOSURE AND FELL DURING THE SECOND HOUR (FIG. 1). THE GREATEST INCREASE (0.8F°) WAS RECORDED DURING EXPOSURE TO THE MOST SEVERE CONDITIONS (40/-/10) AND THE SMALLEST INCREASE (0.2F°) DURING EXPOSURE TO ONE OF THE MORE MILD CONDITIONS (50/100/< 1). AFTER 100 MINUTES OF EXPOSURE, T_R WAS STILL ABOVE CONTROL VALUES IN MOST INSTANCES (FIG. 1). THE INCREMENT IN T_R FROM CONTROL TO PEAK VALUE WAS TREATED STATISTICALLY; THE EFFECTS OF DRY BULB TEMPERATURE ($P < .05$) AND WINDSPEED ($P < .01$) ON T_R WERE SIGNIFICANT, WHEREAS HUMIDITY HAD NO EFFECT.

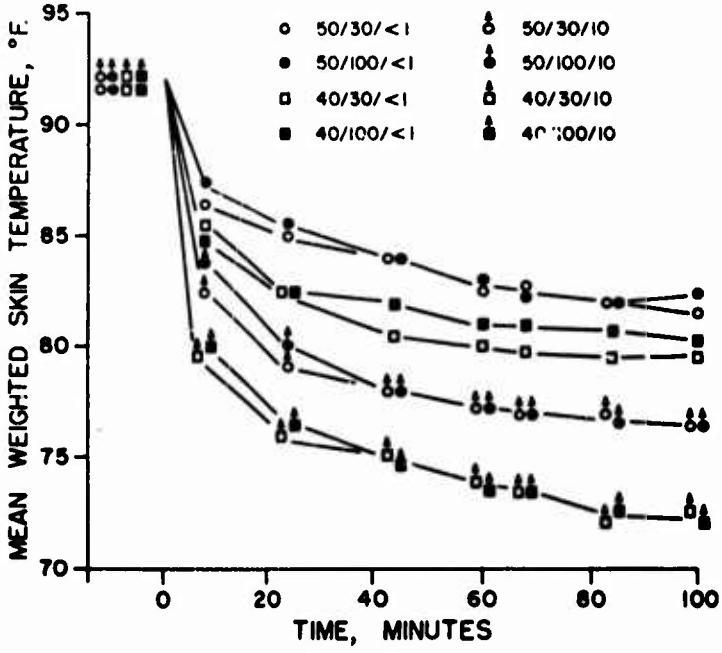

FIGURE 2. MEAN WEIGHTED SKIN TEMPERATURE OF 6 MEN DURING EXPOSURE TO COLD AND HIGH AND LOW HUMIDITIES

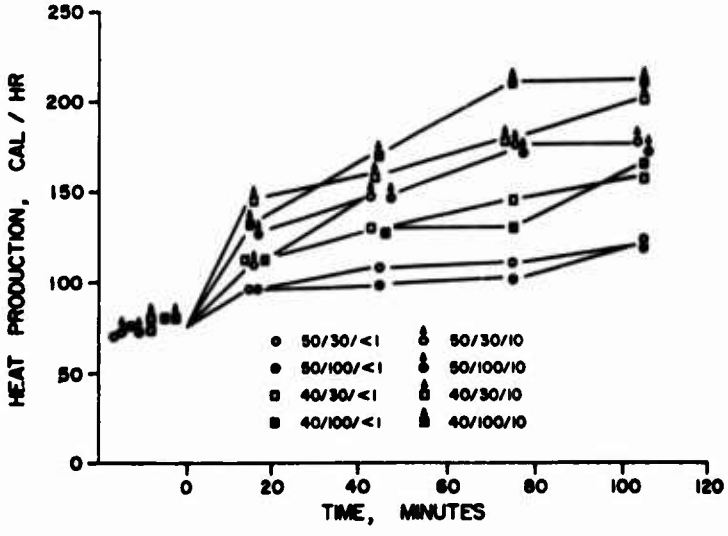

FIGURE 3. HEAT PRODUCTION OF 6 MEN DURING EXPOSURE TO COLD AND HIGH AND LOW HUMIDITIES

MEAN WEIGHTED SKIN TEMPERATURE (T_{MS}) FELL DURING ALL EXPOSURES (FIG. 2). THE DROP WAS MOST RAPID DURING THE FIRST 30 MINUTES (75-80% OF THE TOTAL DROP IN T_{MS} OCCURRED DURING THIS TIME), BECOMING MORE GRADUAL DURING THE REMAINDER OF THE EXPOSURE. EXAMINATION OF FIGURE 2 REVEALS THAT THE SKIN TEMPERATURE CURVES FOR HIGH OR LOW HUMIDITY EXPOSURES FOR A GIVEN SET OF WIND AND TEMPERATURE CONDITIONS ARE VERY SIMILAR. THIS INDICATES THAT THERE IS NO CLEAR-CUT EFFECT OF HUMIDITY ON T_{MS}. FIGURE 2 ALSO SHOWS THE MARKED EFFECTS OF WIND ($P < .01$) AND THE LESS MARKED BUT SIGNIFICANT ($P < .01$) EFFECT OF DRY BULB TEMPERATURE ON T_{MS}.

B. HEAT PRODUCTION

HEAT PRODUCTION, CALCULATED FROM $\dot{V}_{O_2}$, INCREASED DURING ALL EXPOSURES (FIG. 3). THE INCREASE OVER CONTROL VALUES RANGED FROM APPROXIMATELY 50% (AT 50/-/< 1) TO 250% (AT 40/-/10) AFTER 100 MINUTES EXPOSURE. AGAIN THERE WERE MARKED INCREASES IN HEAT PRODUCTION ASSOCIATED WITH THE HIGHER WINDSPEED AND LESS MARKED BUT HIGHLY SIGNIFICANT INCREASES ASSOCIATED WITH THE LOWER AMBIENT TEMPERATURE. FIGURE 3 SHOWS NO EFFECT OF HUMIDITY ON HEAT PRODUCTION. IT IS INTERESTING THAT DURING ALL EXPOSURES APPROXIMATELY 50% OF THE TOTAL INCREASE IN HEAT PRODUCTUION OVER CONTROL VALUES OCCURRED WITHIN 15 MINUTES OF ENTERING THE COLD ROOM.

4. DISCUSSION

THIS STUDY WAS UNDERTAKEN TO DETERMINE WHETHER LACK OF CLOTHING WAS A FACTOR IN PREVIOUSLY REPORTED FAILURES TO DEMONSTRATE A PHYSIOLOGICAL BASIS FOR COLD-WET SENSATIONS IN NUDE MEN (1, 2). THE RESULTS REVEALED A PATTERN OF RESPONSES VERY SIMILAR TO THAT REPORTED FOR NUDE MEN. THIS INDICATES THAT THERE IS NO IMPORTANT INTERACTION BETWEEN CLOTHING AND HUMIDITY THAT WOULD PROVIDE A PHYSIOLOGICAL BASIS FOR THE COLD-WET EXPERIENCE. RENBOURN (4) ALSO WAS UNABLE TO DEMONSTRATE PHYSIOLOGICAL OR SUBJECTIVE DIFFERENCES ATTRIBUTABLE TO HUMIDITY WHEN CLOTHED MEN WERE EXPOSED FOR 100 MINUTES IN AN AMBIENT TEMPERATURE OF 36°F WITH RELATIVE HUMIDITIES OF 50 OR 85%.

ALTHOUGH THE RESULTS OF STUDIES ON BOTH NUDE AND CLOTHED MEN FAILED TO PROVIDE A PHYSIOLOGICAL EXPLANATION FOR COLD-WET "CHILL", IT IS IMPORTANT TO RECOGNIZE THE LIMITATIONS OF CHAMBER STUDIES. AS WE HAVE ALREADY POINTED OUT (1), IT IS POSSIBLE THAT WE HAVE NOT ADEQUATELY COMPARED COLD-WET AND COLD-DRY CONDITIONS. ALTHOUGH WE HAVE ATTEMPTED TO SIMULATE WIND, DRY BULB, AND HUMIDITY CONDITIONS, WE HAVE NOT SIMULATED RADIATION OR PRECIPITATION. EXTENSIVE CLOUD COVER AND LACK OF SOLAR RADIATION ARE CHARACTERISTIC OF COLD-WET ENVIRONMENTS, BUT THE SAME MAY NOT BE TRUE OF COLD-DRY CONDITIONS. THEREFORE, AN ADEQUATE COMPARISON MUST TAKE INTO CONSIDERATION THE QUITE DIFFERENT RADIATION EFFECTS IN THE TWO ENVIRONMENTS. IN THIS STUDY AND OTHERS (1, 2, 4) WALL, CEILING, AND FLOOR TEMPERATURES WERE THE SAME AS AIR TEMPERATURE DURING EXPOSURE TO BOTH HIGH AND LOW

HUMIDITY CONDITIONS. THUS, RADIATIVE LOSS FROM THE BODY TO THESE SURFACES AT A GIVEN AMBIENT TEMPERATURE WAS THE SAME WHETHER HUMIDITY WAS HIGH OR LOW. IF THE DIFFERENCES IN CLOUD COVER, INDIRECT RADIATION, AND SOLAR RADIATION BETWEEN COLD-WET AND COLD-DRY CONDITIONS WERE SIMULATED, IT IS POSSIBLE THAT DIFFERENCES IN PHYSIOLOGICAL RESPONSES WOULD BECOME APPARENT.

ANOTHER FACTOR TO BE CONSIDERED IS THAT DURING LABORATORY STUDIES ALL CONDITIONS (AMBIENT ENVIRONMENT, ACTIVITY LEVEL, ETC.) ARE KEPT CONSTANT AND AN EQUILIBRIUM OR STEADY STATE CONDITION IS APPROACHED. IT IS HIGHLY UNLIKELY THAT SUCH A CONDITION WOULD BE APPROACHED IN ACTUAL FIELD SITUATIONS WHERE ACTIVITY LEVELS, AMBIENT TEMPERATURE, HUMIDITY, ETC., MAY FLUCTUATE WIDELY. SUCH FLUCTUATIONS COULD ALTER CONSIDERABLY THE PHYSIOLOGICAL RESPONSES OF THE SUBJECTS.

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